Modeling the US Healthcare System – Predicting the Consequences of Policy Decisions through Computational Models

David Strip
George Backus
Jim Strickland
Dave Schoenwald

October 4, 2005

Introduction

Crisis is perhaps the most common descriptor of the state of the US healthcare among analysts and commentators. Rapidly increasing costs are placing a financial burden on federal and local governments, businesses, and individual citizens. The National Coalition on Health Care [1] estimates that "in 2004, employer health insurance premiums increased by 11.2 percent - nearly four times the rate of inflation." In spite of the fact that the United States leads the industrialized world in terms of its expenditure on healthcare as a fraction of GDP (see Figure 1) and in per capita spending, it lags the industrialized world in key health indicators such as infant mortality and life expectancy [2]. It is also worth noting that only 45% percent of US citizens have health care coverage whereas in most industrialized nations coverage is universal. Japan, with one of the lowest health care costs among industrialized nations, also has one of the longest life expectancies. For example, the life expectancy of a Japanese woman is over 85 years while that for their US counterpart is less than 80 years [3].

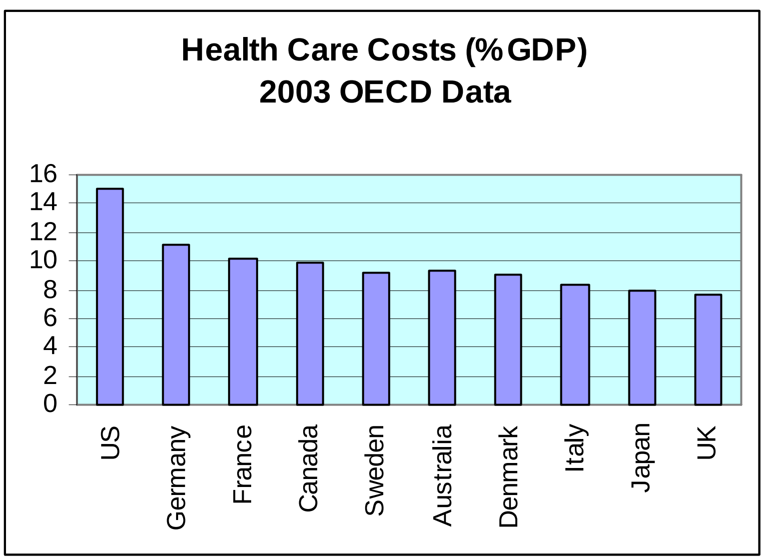

Figure 1 International Health Care Costs [2]

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000

Although any number of ideas (sometimes conflicting) have been proposed as potential solutions, predicting the impact of these ideas on healthcare costs and the adequacy of patient care has been nearly impossible. It has been particularly frustrating to policy-makers and the general public that so many changes to the system have resulted in nearly the opposite of their intended effect, often increasing costs while reducing the overall quality of care. Even the value and causes of these increased costs are often poorly understood.

The health care system is characterized by complex interactions between large numbers of patients, hospitals, insurance companies, governing bodies, etc. High performance computing coupled with agent-based modeling will provide a tractable simulation of the US healthcare system as opposed to more traditional methodologies that would simply be overwhelmed by the complexities of this problem. Successful development of such a tool would be extremely useful in performing studies that capture the interplay, cost dynamics, and merits associated with various policy decisions, methods of healthcare delivery, etc.

Background

The important role of engineering in helping to understand and mitigate problems in the US healthcare industry has been acknowledged by the National Academies. The National Academy of Engineering NAE and the National Academies Institute of Medicine IOM formed a collaborative effort in 2001 to "identify and assess opportunities for engineering applications and research to improve performance of the health care delivery system" [4]. The study recognizes the potential for systems engineering techniques to contribute to healthcare delivery, but even this study stops short of the policy analysis level where many of the most important gaps remain.

A recent workshop [5] funded by a grant to the University of British Columbia from the Peter Wall Institute and sponsored in part by the Canadian Institutes of Health Research and the Canadian Center for Epidemiology and Evaluation, provides insight into the present role of modeling and simulation of healthcare systems. Abstracts from presentations of invited speakers indicate that the modeling focus is on simulations at the scale of the local hospital and its departments such as patient flow, cardiac care, outpatient care, emergency room operation, operation of buildings, etc. One exception to this was an abstract concerning an effort to obtain a planning tool for setting the number of physicians that need to be trained in Canada each year so as to meet but not exceed demand.

There are a number of healthcare studies that have been conducted using agent-based modeling. In a recent review paper by Nealon and Moreno [6], they note that agent-based simulations have been applied to many different kinds of problems in the health care domain that include patient scheduling, organ transplant management, community care, information access, decision support systems, training, internal hospital tasks, and senior citizen care. In general, while agent-based modeling has seen widespread use in

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000

the healthcare industry, simulations of health care for a region or country do not presently exist due to the enormous computational complexity. It is, however, easy to conceive that such a model can be constructed and successfully used when high-performance computing forms an integral part of the methodology.

Modeling Approach

Historically, systems as complex as the U.S. health care system have been modeled using methods that aggregate the various players into a relatively small number of components whose interactions are expressed by closed form mathematical equations. The attractiveness of this approach is the simplicity of the computational model. Unfortunately, the cost of this simplicity leads to the loss of detail inherent in aggregate models. Often the actions of individuals lead to composite behaviors that are not anticipated and therefore cannot be expressed by such models.

Advances in computing, especially the advent of massively parallel systems, have enabled a second approach called agent-based modeling. In this approach we model each individual decision-maker in a system capturing their behavior and interactions with other decision-makers. By instantiating thousands (or even millions) of these agents in one model, a realistic simulation of a large-scale system can be achieved. The interactions between the agents are automatically captured by the model, which provides the many feedback loops present in such a large and complex system. The principal advantage of this modeling approach is the ability to define and analyze individual decision-makers' behavior and its effects on the entire system. These models are being used at Sandia to analyze military logistics of globally deployed weapons systems [7], regional and national economic performance in the face of infrastructure disruptions [8-10], consumer and corporate economic confidence in the face of terrorist acts [11-14], and economic impacts of global climate change [15].

The modeling of the U.S. health care system is a complicated endeavor but one in which Sandia National Laboratories has the expertise to develop such a model by leveraging its experience in high performance computing, agent-based modeling, human behavior, and economics.

References

1. National Coalition on Health Care, http://www.nchc.org/facts/cost.shtml
2. Organisation for Economic Co-operation and Development, http://www.oecd.org
3. Vaupel, J.W., Sanford, T, Testimony before the Senate Special Committee on Ageing, Hearing on "The Future of Human Longevity: How Important Are Markets and Innovation?" June 3, 2003. http://www.pubpol.duke.edu/centers/ppa/Links/Vaupeltestimony603.pdf
4. Engineering and the Health Care System, http://www.nae.edu/nae/engecocom.nsf/(weblinks)/NAEW-4NHM8R?OpenDocument

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000

5. Modeling Health Care Systems: Workshop on Linking Operations and Health Services Research, August 31-September 4, 2005. http://www.mhcs.pwias.ubc.ca/
6. J. Nealon and A. Moreno, "Agent-Based Applications in Health Care," Applications of Software Agent Technology in the Health Care Domain, Birkhauser Verlag, Berlin, 3-18, 2003.
7. Schoenwald, David A. and Robert M. Cranwell, "Development of an Enterprise-Scale Agent-Based Autonomic Logistics Simulation Model", Sandia National Laboratories Laboratory Directed Research & Development (LDRD) FY2005 Annual Report, September 2005.
8. Barton, Dianne C, Eric D Eidson, David A Schoenwald, Kevin L Stamber, Rhonda K Reinert, "Aspen-EE: An Agent-Based Model of Infrastructure Interdependency," SAND Report, December 2000.
9. Barton, Dianne C., and George Backus "An Example of Infrastructure Interdependency Analysis: Local, Regional, and National Economic Impacts", SAND Report 2002-0911, 2002
10. Schoenwald, David A., Dianne C. Barton, and Mark A. Ehlen, "An agent-based simulation laboratory for economics and infrastructure interdependency.," Proceedings of the 2004 American Control Conference, Boston, MA, July 2004 (also SAND2004-2591C).
11. Sprigg, James A, Mark A Ehlen, "Full Employment and Competition in the Aspen Economic Model: Implications for Modeling Acts of Terrorism," SAND Report, November 2004.
12. Hand, Michael S, Paul J Paez, James A Sprigg Jr., "On the Need and Use of Models to Explore the Role of Economic Confidence: A Survey," SAND Report, April 2005.
13. Sprigg Jr., James A, Craig R Jorgensen, Richard J Pryor, "Approach and Development Strategy for an Agent-Based Model of Economic Confidence," SAND Report, August 2004.
14. Sprigg Jr., James A, "Market Disruption, Cascading Effects, and Economic Recovery: A Life-Cycle Hypothesis Model," SAND Report, November 2004. Dianne C. Barton, Eric D. Eidson, David A. Schoenwald, Roger G. Cox, and Rhonda K. Reinert, "Simulating Economic Effects of Disruptions in the Telecommunications Infrastructure", SAND2004-0101, January 2004.
15. Backus, George, et. al, Climate Change Plan for Canada, 2002, http://climatechange.gc.ca/english/publications/plan_for_canada/

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000